THE PRE-DEPOSITIONAL FORMATION OF SOME LEAF IMPRESSIONS

by ROBERT A. SPICER

ABSTRACT. Observations show that an inorganic sedimentary encrustation may be built up on plant leaves within a few weeks after entry into a depositional environment. Such an encrustation may be the basis of a detailed impression fossil. SEM examination and X-ray microanalysis of this encrustation on freeze-fractured, freeze-dried leaves reveals preferential deposition of fine-grained, iron-rich material that faithfully replicates the epidermal surface detail of the leaf. By analysis, fossil-leaf impressions from the Upper Cretaceous Dakota Sandstone of Kansas are shown to have a similar elemental composition. A possible biogenic origin for the surface encrustation is suggested.

IN a recent paper Schopf (1975) reviewed the forms in which plants may be preserved as fossils. They may be preserved by cellular permineralization (petrifaction) in which three-dimensional cellular detail is retained, by the remains becoming compressed in the vertical plane often accompanied by coalification of the original tissues (compression), as external or internal moulds and occasionally bulk replacement by inorganic material (authigenic preservation), or as unaltered hard parts (duripartic preservation). The factors governing the type of fossil that will be formed are a combination of the nature of the plant material, the events both preceding and following burial, and the physical and chemical characteristics of the entombing sediment. The term impression fossil may be loosely applied to that which remains when the coalified organic remains in a compression fossil (the anthracolemma) are removed from the rock (either by the palaeobotanist or by weathering) or to the surface mould of a leaf in a concretionary nodule (authigenic fossil). In this paper both meanings are implied.

Impression fossils have in the past received less detailed study than some of the other forms of fossil primarily because they lack organic remains and retain only surface detail. However, with improved study techniques (particularly the examination of silicone rubber impression replicas in the Scanning Electron Microscope (SEM) (Chaloner and Gay 1972) and the increasing taxonomic use of foliar venation and cuticular characters (see review in Dilcher 1974)) more attention is being paid to the impression fossil.

Schopf (1975) wrote: 'By authigenic preservation fossil fragments commonly have been encased by cementing materials during the soft mud stage soon after burial. The requirements are deposition in fine textured sediment and commonly, but not invariably, early precipitation of authigenic minerals in sediment pore space around the organic fragment.' Krystofovich (1944) recognized that plant material deposited in stagnant pools often becomes coated with a thin encrustation of inorganic material even before burial. He suggested that carbon dioxide given off by the decaying vegetable matter might cause chemical precipitation of the film (which he termed primary or initial crust) and that subsequent thickening of this film could lead to the eventual preservation of the remains. While studying the potential formation of plant fossil beds in Recent aquatic environments (Spicer 1975), it was similarly noted

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that many leaves became encrusted with a layer of inorganic material within a few weeks after entry into a freshwater stream or lake environment but before final deposition had taken place. The sediment crust was often so coherent that it could not be removed by washing and adhered to the leaf even during violent transport. This paper described the nature of the sedimentary crust, as revealed by X-ray microanalysis in the SEM, makes a comparison with a similar fossil impression, and suggests a possible biogenic origin for the encrustation.

THE FIELD SITE

All the modern leaves studied were collected from a freshwater fluviolacustrine environment in the grounds of the Imperial College Field Station at Silwood Park, near Ascot, Berkshire, England. Here a small stream drains from iron-rich Tertiary Bagshot Sands and flows into Silwood Lake where it has formed a delta, the surface sediments of which are composed mainly of flocculent ferric hydroxide ($Fe(OH)_3 . nH_2O$) similar to that described by Coey and Readman (1973). Sheaths of the iron bacterium *Sphaerotilus* sp. were abundant in both stream and delta surface sediment, together with a small quantity of quartz sand grains and diatom frustules, and are figured in Muir *et al.* (1974). Leaves for study were collected from both fluviatile and deltaic surface sediments.

Specimens of fossil-leaf impressions from the Upper Cretaceous Dakota sandstone in Kansas were borrowed from the Museum of Paleontology of the University of California at Berkeley.

METHOD

Modern leaves were prepared under both field and laboratory conditions in the following manner.

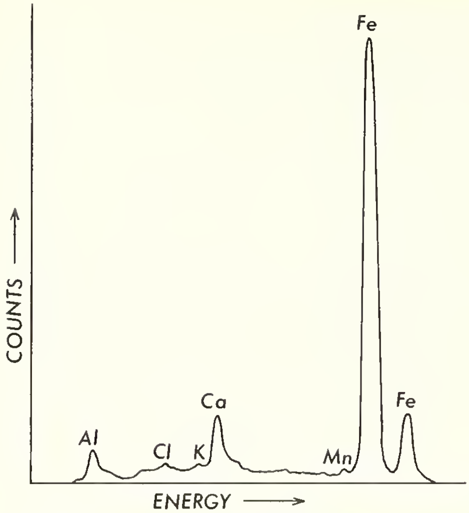
A rectangular (approximately 7 mm $\times$ 10 mm) piece of intercostal lamina was cut from the unwashed leaf using scissors, which facilitated cutting the leaf with a minimum of contamination of either epidermal surface. This piece of leaf was then mounted vertically in a groove that had been previously cut in an aluminium scanning electron microscope stub and the two halves of the stub were squeezed together so as to lightly grip the leaf. Two small nicks were made in the leaf approximately 1 mm above the surface of the stub to aid fracturing in the desired position. The mounted leaf was then plunged into 'Arcton 12', held at its melting point of -155 °C., and, with the aid of stainless steel forceps, the leaf was fractured parallel to the stub surface. The stub and leaf were then rapidly transferred to the specimen block (pre-cooled to -70 °C.) of a freeze dryer (Spicer *et al.* 1974) and the leaf was freeze dried at -70 °C. for 48 hours. When dry the specimen was vacuum coated with carbon and examined in a Cambridge Stereoscan MkIIA fitted with an ORTEC SiLi energy dispersive X-ray detector.

Fossil specimens were mounted directly on to aluminium stubs and coated with carbon before being examined in a Cambridge S180 SEM with an EDAX SiLi energy dispersive X-ray detector.

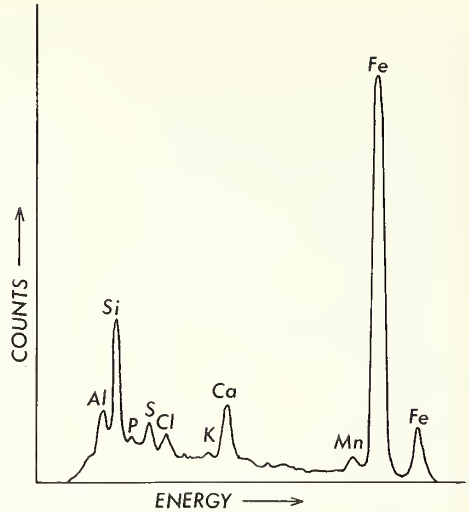
TEXT-FIG. 1. An air-dried leaf of *Fagus sylvatica* recovered from iron-rich stream sediments. The surface encrustation has curled back from the leaf during drying to reveal a faithful impression of the leaf surface. ×900.

RESULTS AND DISCUSSION

Text-fig. 1 illustrates the nature of the sediment coat on the lower epidermal surface of a leaf of *Fagus sylvatica* L. extracted from the surface of the deltaic deposits. Little fungal breakdown is evident in the tissues of the leaf but the coherent encrustation has already formed. This figure shows a partially air dried *F. sylvatica* leaf from the stream waters. The partial air drying, whilst leading to some tissue collapse, has resulted in the curling back of the encrustation revealing faithful replication of the epidermal cellular detail. The results of the X-ray microanalysis of the encrustation are presented in text-figs. 2 and 3. It can clearly be seen that the spot analysis (i.e. with a stationary electron beam) of the external surface of the sedimentary crust (text-fig. 3) exhibits large silicon and iron peaks as well as pronounced sulphur and chlorine peaks. By comparison the spot analysis of the sedimentary encrustation originally in contact with the leaf surface (text-fig. 2) exhibits no silicon peak and the sulphur and chlorine peaks are considerably reduced. Some, possibly all, of the attenuation of the sulphur and chlorine peaks may be due to X-ray absorption because the analysis was of necessity restricted to a portion of the specimen not directly 'seen' by the detector. The loss of the silicon peak, however, is so complete that it is unlikely that such an effect could explain its absence. Rather the analysis indicates that the sediment in contact with the leaf is almost entirely composed of iron-rich material, most probably finely divided ferric hydroxide. After this deposit had formed on the leaf, the coarser fractions of the sediment, namely the quartz grains and diatom frustules, became incorporated. Thus the epidermal features of a leaf may become preserved in the fine-grained iron flocks in spite of the coarser nature of the bulk sedimentary components.



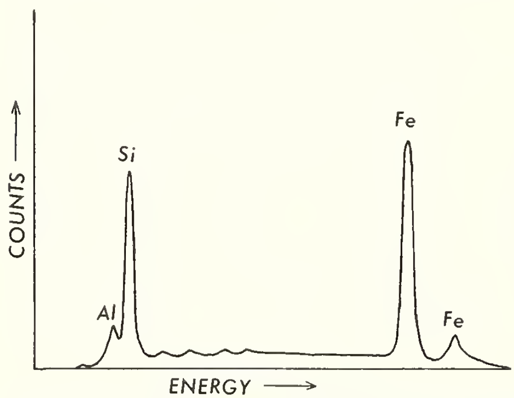
TEXT-FIG. 2. Results of the X-ray microanalysis of the surface of the encrustation originally in direct contact with the leaf of *Fagus sylvatica*.



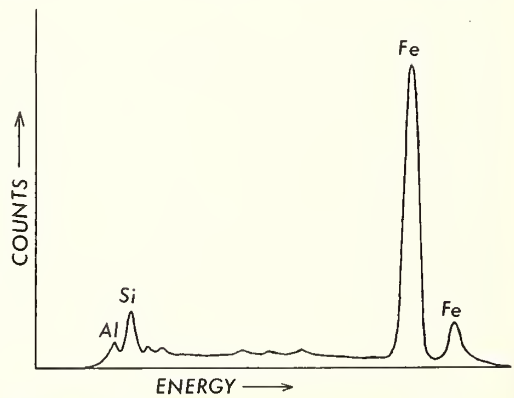
TEXT-FIG. 3. X-ray spectrum from the analysis of the encrustation. The electron beam was positioned on the surface of the encrustation not originally in contact with the leaf surface (i.e., exposed to the stream waters).

Krystofovich (1944) noted that often good quality plant impressions may be found even in coarse-grained sediments and cited examples from the Paleocene and Eocene floras of the Ukraine and Volga and the South Urals. Similar examples may be found in the Dakota sandstone fossils and analyses of these impressions yield elemental compositions comparable to those observed in the Recent material.

The X-ray spectrum of a leaf impression from the Dakota sandstone (text-fig. 5) exhibits a very high iron peak compared to that of silicon. Text-fig. 4 is a spectrum



TEXT-FIG. 4. X-ray spectrum from the area of sediment matrix which surrounds the Dakota sandstone fossil leaf impression.



TEXT-FIG. 5. X-ray spectrum obtained from the surface of the Dakota sandstone leaf-impression fossil.

obtained from the sedimentary matrix of the same specimen; there is a very high silicon peak in relation to the iron. This seems to indicate that the leaf impression was composed mainly of iron-rich material. The impression itself unfortunately showed little cellular detail except along veins where elongated cells with their longest axis aligned parallel to the vein could be seen. While the quality of the impression is not as good as some described in the literature (e.g. Chaloner and Collinson 1975), it is evident that the impression itself is made up of much finer-grained material than that of the surrounding matrix. A number of analyses were carried out on this and other specimens and all gave similar results.

CONCLUSIONS

High iron concentrations on a fossil impression do not necessarily mean that an encrustation was laid down prior to deposition and burial. It is well known that many minerals, particularly those of iron, will form around an organic nucleus during diagenesis although the mechanism for this process is not well understood (Tarr 1921; Edwards and Baker 1951; and Schopf 1975). Too close a comparison between the Silwood leaves and the Dakota sandstone fossils is not warranted because they were probably formed in different depositional environments. Most of the Dakota sandstone has been interpreted as marginal marine (Lee 1923; Waagé 1959) laid down by an advancing Cretaceous sea and as such represents a variety of local depositional environments. Nevertheless, it has been demonstrated that such an encrustation, having the same elemental composition as that which may be observed in the fossil state, may develop before the leaf has finally been deposited, even within a few weeks after entry into a stream or lake environment.

The effect of such a coating may be to limit biological breakdown either by invertebrate particle feeders or micro-organisms. The cuticle surface would certainly be partially protected from abrasion during transport with the result that fine surface detail could be preserved.

The proposition of Krystofovich that precipitation of sediment at the plant surface is caused by carbon dioxide given off by the decaying organic matter may not account for the formation of the ferric hydroxide encrustation observed in the Silwood environment because the encrustation was also seen to occur on such biologically inert substances as a glass bottle and nylon rope. If carbon dioxide was in some way causing the precipitate then the encrustation would be expected to be greater on the decaying plant matter than the inert material, a phenomenon that was not observed. The mechanism of deposition of this early encrustation has not yet been established but may result from the activity of iron bacteria at or on the leaf surface. The close association of micro-organisms and mineral deposition has been frequently reported (Stocks 1902; Kuznetsov *et al.* 1963; Love and Murray 1965; and Ehlers *et al.* 1965) and it seems likely that the role of micro-organisms in the mineral preservation of both animal and plant remains may well be greater than was at one time thought.

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